Astronomy & Astrophysics manuscript no.
h3240

The Galactic Centre Source IRS 13E: a Post-LBV Wolf-Rayet Colliding Wind Binary?

R.F. Coker[1], J.M. Pittard[1], and J.H. Kastner[2]

[1] Department of Physics and Astronomy, University of Leeds, Leeds LS2 9JT UK
[2] Chester F. Carlson Centre for Imaging Science,
Rochester Institute of Technology, 54 Lomb Memorial Drive, Rochester, NY 14623

Received 2001 / Accepted 2001

Abstract. IRS 13E is an infrared, mm and X-ray source in the Galactic Centre. We present the first *Chandra* X-ray spectrum for IRS 13E and show that it is consistent with a luminous and highly absorbed X-ray binary system. Since the X-ray luminosity is too large for a solitary star, our interpretation is that of an early-type long-period binary with strong colliding winds emission. This naturally explains the observed X-ray spectrum and count rate as well as its lack of significant short term variability. Due to the short lifetime of any nebula 0.2 pc from the putative central super-massive black-hole, we argue that the primary of IRS 13E has exited the LBV phase in the last few thousand years.

Key words. X-rays: stars – Stars: Wolf-Rayet – Stars: individual: IRS 13E

1. Introduction

It is probable that Sgr A*, the compact, nonthermal radio source at the Galactic Centre (GC) is a 2–3$\times10^6 M_\odot$ black-hole (for a recent review see Melia & Falcke 2001). Pervading the central parsec of the Milky Way is a cluster of a few dozen HeI and early-type stars (Sellgren et al. 1990; Genzel et al. 1996). One of these stars, IRS 13E, has been identified as a Wolf-Rayet (WR) star with spectral class WN10 (Najarro et al. 1997) and lies within IRS 13, a compact HII region. The IRS 13 complex, dominated by IRS 13E, has been identified as a HeI, Pa-α, [FeIII], and HeII line source (Lutz et al. 1993; Libonate et al. 1995; Krabbe et al. 1995; Stolovy et al. 1999).

Motivated by the conjecture (Coker & Pittard 2000) that IRS 13E is an X-ray binary, we present here an analysis of *Chandra* Advanced CCD Imaging Spectrometer (ACIS) GC observations (obs ID=242) of this source. Details of the observations can be found in Baganoff et al. (2000, 2001a,b). The X-ray source $\sim 4''$ west-southwest of Sgr A* is the only source in the central parsec that has been associated with a previously known stellar object, IRS 13E. Since IRS 13E appears as an X-ray source while the other early-type stars in the central parsec do not, IRS 13E must harbor a distinctive object.

Based on its lack of significant variability at all wavelengths and its strong X-ray luminosity with characteristic $kT \simeq 1.0$ keV, we argue that IRS 13E is most likely an early-type wide binary system with the primary only recently having exited the luminous blue variable (LBV) phase of evolution.

2. Source Identification

As discussed in Coker & Pittard (2000), we identify the X-ray source $3''$ west[1] and $1.5''$ south of Sgr A* with the infrared source IRS 13E. However, further identification is far from clear. In K-band observations the IRS 13E complex is resolved into 3 components (Ott et al. 1999): IRS 13E1 ($m_K = 10.26$), IRS 13E2 ($m_K = 10.27$), and IRS 13E3 ($m_K = 10.31$) (Fig. 8 of Paumard et al. 2001). However, these objects do not match up with mm observations, which show a different set of 3 components, some of which are extended (Fig. 2 of Zhao & Goss 1998). We previously (Coker & Pittard 2000) identified the mm sources IRS 13E and IRS 13W with the IR sources IRS 13E1 and IRS 13E2, respectively, but careful astrometry shows that none of the K-band sources are coincident with the mm sources (Maillard 2001; private communication). This implies the mm sources may not be stellar; the relative locations of the mm and IR sources open the possibility that the radio sources are due to the colliding winds of a binary – or even triple – system. However, it appears that in agreement with Paumard et al. (2001), IRS 13E3

Send offprint requests to: R.F. Coker,
e-mail: `robc@ast.leeds.ac.uk`

[1] At a distance of 8.0 kpc (Reid 1993), $1'' \simeq 0.04$ pc.

is slightly extended so its identification as a single stellar source is unclear.

Paumard et al. (2001) identify IRS 13E3 as the HeI source while Najarro et al. (1997) identify IRS 13E1 as the HeI source. However, NICMOS data, taken in March 1998, show (Stolovy 2001; private communication) that IRS 13E1 has very little (if any) excess emission at 1.87μm while IRS 13E3 has some excess and IRS 13E2 has a strong excess. Since a 1.87μm excess probably represents a blend of Pa-α, HeI and HeII emission lines, IRS 13E2 is very clearly the dominant Pa-α and HeI source of the IRS 13E complex.

Paumard et al. (2001) also report that their June 1998 observations show IRS 13E3 is slightly elongated and much dimmer ($m_K = 11.73$) than the other two components. But the series of observations by Ott et al. (1999), undertaken from 1992 to 1998, show that all three components are of nearly equal magnitude and that IRS 13E3 (their source 21) in particular is non-variable at the level 0.2 mag. Further, K-band images taken in 1993 and 1994 (Tamblyn et al. 1996) which do not resolve the IRS 13E complex have $m_K = 9.1$ mag, fully consistent with the 3 equal sources with $m_K = 10.3$ mag seen by Ott et al. (1999). The cause of this ~ 1.5 mag discrepancy is unclear.

Although not critical to our results, in this paper we will identify the WN10 star with IRS 13E2 and the X-ray source with the IRS 13E complex as a whole. The components of IRS 13E are separated from each other by $\sim$ 0.1–0.2$''$ in projection, so that, given the $\sim 0.5''$ resolution of *Chandra*, we lack sufficiently good positional references for precise identification of the X-ray source.

3. The X-ray Data and Spectral Fitting

Chandra observed the GC in September 1999 and again in October 2000 (Baganoff et al. 2000, 2001a). Here we present detailed analysis of only the first epoch of observations. We used standard data processing tools available from the Chandra X-ray Center (CXC) as part of the CIAO v2.1 package[2] to extract spectra of the X-ray source and of adjacent background, and to determine the appropriate response matrix and ancillary response (effective area) function for the source extraction region. The source spectrum was extracted by binning events lying within a 2.5$''$ radius circle centered on IRS 13E; the background spectrum was extracted from within three 2.5$''$ radius circles adjacent to and immediately north, south, and west of this source region. We avoided the region immediately to the east of IRS 13E, as it is dominated by intense emission from Sgr A*. Within the source region we find 137 counts in 46 ksec net integration time. The background regions contain $\simeq 45$ counts in an equivalent area, such that the background-subtracted count rate is 0.002 cts s^{-1}. Within the limited Poisson statistics, the X-ray flux from IRS 13E appears to remain constant between the two epochs. In addition, within the two ~ 50 ksec observations, IRS 13E is not seen to vary.

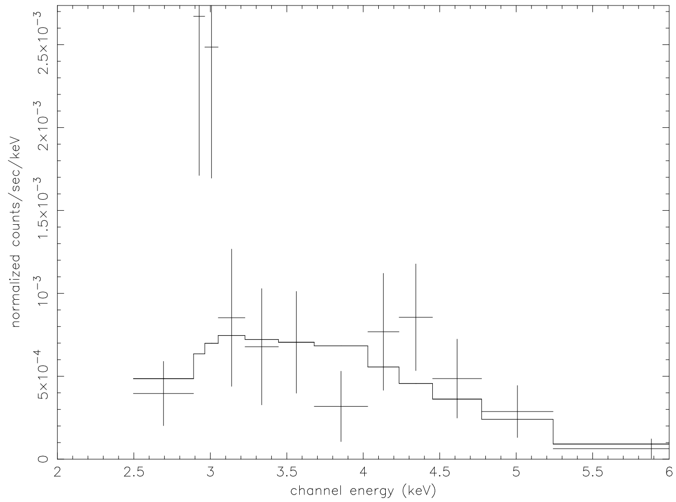

Fig. 1. A plot of counts per second per keV versus energy for the data (crosses) and best-fitting model (solid line).

We fit the data with the MEKAL (Mewe et al. 1985) model in XSPEC[3]. This is a thermal plasma model and assumes optically thin X-ray line and continuum emission. We account for an external absorption column by simultaneous application of the *wabs* model.

In fitting the spectral X-ray emission, we vary three parameters: the X-ray luminosity in the 0.2-10 keV band ($L_{\rm x}$), a characteristic temperature (kT) of the X-ray emitting gas, and the line-of-sight column density ($N_{\rm H}$). The metallicity, Z, of the stars in the central parsec is not well known; ISM gas phase abundances are roughly twice solar (Simpson et al. 1995) while that of GC red supergiants is only solar (Carr et al. 2000; Ramírez et al. 2000). The goodness of fit does not change significantly when the global abundance is varied so we have assumed solar metallicity for simplicity.

Spectral models can be fitted to data with low counts using the Cash statistic (Cash 1979). However, a background cannot be subtracted using this method. We therefore employ the χ^2 fit statistic to our background-subtracted data, rebinned to a minimum of 10 cts per bin.

4. Results & Discussion

Fig. 1 shows the ACIS data along with the best-fitting model, which yielded $\chi^2_\nu \simeq 1.5$, formally a somewhat poor fit. The best-fitting parameters are listed in Table 1. Inspection of Fig. 1 shows that our model underestimates the evident line emission at $\simeq 3$ keV and slightly overestimates the emission at $\simeq 3.75$ keV. Some of this may be due to poor statistics but the strong emission near 3 keV may also reflect a complex metal abundance.

Our fit suggests $N_{\rm H} \simeq 15\times 10^{22}$ cm^{-2}. This is somewhat larger than the 5–10 $\times\ 10^{22}$ cm^{-2} found for

[2] For details see http://cxc.harvard.edu/ciao/index.html

[3] Distributed and maintained by HEASARC

Table 1. Computed Model for IRS 13E and Arches A2

	IRS 13E	Arches A2[a]
Z	1.0	2.6[b]
L_x ($\mathrm{L}_\odot$)	7	20
kT (keV)	1.0 ± 0.4	1.0 ± 0.5
$N_\mathrm{H}(10^{22}$ cm$^{-2})$	15 ± 5	12 ± 2

a) from Yusef-Zadeh et al. (2001b)
b) averaged Z over Si, S, Fe, Ar, and Ca

Sgr A* (Baganoff et al. 2000, 2001a), implying that there is additional substantial absorption close to the IRS 13E X-ray source. If so, and if the size of the X-ray source is comparable to the $\simeq 0.1''$ diameter region seen in mm observations, then the characteristic density of the gas surrounding IRS 13E is consistent with a colliding wind binary (CWB) system (Stevens et al. 1992) but somewhat more dense than LBV ejecta (Seward et al. 2001). However, some of our estimated column to the GC may be due to dust (Baganoff et al. 2001a) since, unlike most of the massive stars in the central parsec, the IRS 13 complex is enshrouded by warm dust (Rieke 1999). Similar large amounts of dust are seen around "cocooned" stars located in the Quintuplet Cluster that is 50 pc from Sgr A* in projection (Figer et al. 1999); although these stars are probably WCd type stars, this is not yet certain (Moneti et al. 2001).

The fitted characteristic temperature, $kT \simeq 1.0$ keV, is consistent with the shocked winds of a CWB system such as a WR+O. In contrast, an accretion source with a compact companion such as in a massive X-ray binary (MXRB) system, would typically have a harder spectrum (*e.g.*, Schlegel et al. 1993). Also, a solitary massive O-star typically has a characteristic temperature of only $\sim$ 0.5 keV (Chlebowski et al. 1989). In the case of a CWB, the characteristic temperature represents a global average of the hot, shocked colliding winds, while X-ray emission from a MXRB probes the accretion disk. On the other hand, the X-ray emission from LBVs is not well known; only η Car, a suspected binary whose primary is an LBV, has a well-determined spectrum. The emission from η Car is a combination of hard ($kT \sim 5$ keV) compact emission from the star and softer ($kT \sim 0.5$ keV) extended emission from ejecta (Seward et al. 2001). However, as a binary, the X-ray emission from η Car may not be typical of solitary LBV stars.

The absorption-corrected X-ray luminosity of IRS 13E in the 0.2-10 keV band is found to be $L_\mathrm{x} \simeq 7\,\mathrm{L}_\odot$. Although larger luminosities are found for the brightest early-type binary systems (e.g. WR 140 and, assuming binarity, η Car; van der Hucht et al. 1994; Corcoran et al. 2001), $L_\mathrm{x} \simeq 7\,\mathrm{L}_\odot$ is still brighter than the typical CWB system. However, this is not wholly unexpected given the large mass-loss rate and wind velocity of IRS 13E2 (Najarro et al. 1997). In contrast, such an X-ray luminosity is a bit low for a MXRB with an accreting compact source unless the system has an unusually long period. Additionally, the X-ray luminosity of a MXRB generally varies on short time-scales. Therefore, due to its low luminosity, lack of variability, and relatively soft spectrum, it is somewhat unlikely that IRS 13E contains a short period MXRB.

The lack of variability also makes it unlikely that the X-ray emission from IRS 13E is due to either a flaring proto-star or young stellar object (YSO). The estimated intrinsic X-ray luminosity is also considerably higher than any known YSOs (*e.g.*, Garmire et al. 2000). However, Clénet et al. (2001) show that the K-L colour of the IRS 13 complex as a whole is consistent with the presence of YSOs.

Single massive stars seem to obey the rough relation $\log_{10}\left(L_\mathrm{x}^\mathrm{ISM}/L_\mathrm{bol}\right) = -7 \pm 1$ (Pallavicini et al. 1981), although more recent work (Chlebowski & Garmany 1991; Moffat et al. 2001) suggests the scatter may be more substantial and the ratio may be half a dex larger. $L_\mathrm{x}^\mathrm{ISM}$ is the X-ray luminosity corrected for extinction due to the ISM but not for intrinsic extinction (Waldron et al. 1998). If we assume that $N_\mathrm{H}^\mathrm{ISM} = 10^{23}$ cm^{-2}, then our model for IRS 13E results in $\log_{10}\left(L_\mathrm{x}^\mathrm{ISM}/L_\mathrm{bol}\right) = -7$, no greater than solitary X-ray sources. CWB systems tend to have an enhanced X-ray to bolometric luminosity ratio by a factor of a few compared to solitary stars, but there is considerable variation. Possible contamination and large error bars in determining $\log_{10}\left(L_\mathrm{x}^\mathrm{ISM}/L_\mathrm{bol}\right)$ for IRS 13E2 make it difficult to draw any conclusions concerning binarity using this ratio. For example, it may be that very little of the extinction is intrinsic to the IRS 13E system (see below); this would result in a substantially larger $L_\mathrm{x}^\mathrm{ISM}$.

We must caution that given the low signal-to-noise of the data, the best-fitting parameters are not very well constrained. For example, forcing $kT = 5$ keV and varying only N_H and L_x results in a fit with $\chi^2_\nu = 1.9$. However, based on observations of other objects in the GC it is probable that $N_\mathrm{H}^\mathrm{ISM} \gtrsim 10^{23}$ cm^{-2}. Given this additional constraint, we can say that $L_\mathrm{x} \gtrsim 1\mathrm{L}_\odot$ and $kT \lesssim 1.8$ keV.

Also shown in Table 1 are the results for the bright soft component of source A2 of the Arches cluster located $\simeq 25$ pc from Sgr A* (Yusef-Zadeh et al. 2001a,b). The fit to this source implies a higher than solar metallicity for a range of metals. Although we assume solar metallicity for IRS 13E, the peaks near 3 and 4.25 keV in Fig. 1 are possible indicators of high S and Ar content. Enhanced abundances for these elements lead to a slightly better fit ($\chi^2_\nu = 1.3$) but due to the low number of counts in our spectrum, we do not attribute much significance to this. Our column density, characteristic temperature, and X-ray luminosity are close to that for A2, which is also coincident with a known IR stellar source, suggesting the objects are of similar nature.

In short, even given the large uncertainties, the X-ray luminosity and characteristic temperature of IRS 13E do not favour a single object (O-star, WR star, LBV, or YSO). Also, the lack of variability is inconsistent with a short-period MXRB. On the other hand, all of the characteristics of IRS 13E are fully consistent with a long-period CWB system.

5. Evidence for a Recent Post-LBV System

Although many significant details of massive star evolution remain to be addressed, the present picture of massive star evolution is that stars with zero-age main sequence (ZAMS) mass $\gtrsim 25$ M$_\odot$ pass through the WR stage. The evolutionary sequence for the more massive stars ($M_{\rm ZAMS} \gtrsim 40$ M$_\odot$) is thought to be (Walborn 1989; Langer et al. 1994):

O $\rightarrow$ H-poor WN $\rightarrow$ LBV $\rightarrow$ H-free WN $\rightarrow$ WC $\rightarrow$ SN .

Most stellar evolution models suggest it takes more than 5×10^5 yrs for a massive star to evolve through the entire WR sequence, with the LBV phase taking more than 10^4 yrs (Stothers & Chin 1996). While in the LBV phase, massive stars are thought to repeatedly move back and forth across the HR diagram, being bluer in quiescence and redder during major eruptions. More than 70% of the LBV phase is spent in quiescence (van Genderen 2001). However, some evolutionary models suggest that extremely massive stars ($M_{\rm ZAMS} \gtrsim 60$M$_\odot$), particularly those with high metallicity or large rotation rates (Meynet & Maeder 2000), may never become true LBVs (Crowther et al. 1995) or even WRs (Mowlavi et al. 1998).

Since IRS 13E2, the presumed HeI line source (see §2), is spectrally a late-type WN star (van der Hucht 2001), it can be either a pre- or post-LBV object. As chemically the source has a large He to H ratio (Najarro et al. 1997), IRS 13E2 is probably a post-LBV object. There are thought to be a minimum of 6 WC[4] stars in the central cluster (van der Hucht 2001) so at least some cluster members, presumably those with the largest ZAMS mass if the cluster is coeval, have already gone through the LBV phase. This is particularly noteworthy since the ZAMS mass of IRS 13E2 is thought to be as high as $\simeq$ 120 M$_\odot$ (Schaller et al. 1992), implying that the ZAMS mass of the 6 WC stars is even higher. Some of the HeI stars in the central cluster are comparatively high in H; they may be pre-cursor LBVs. If the statistics of LBVs versus WRs in the LMC is comparable to that in the GC, one would expect ~ 1 LBV out of a population of a few dozen WR stars (Humphreys & Davidson 1994; Parker 1997).

The H-poor WN stars, being pre-LBV, are more massive, more luminous and larger than the H-free WN stars. As the terminal velocity of radiatively driven winds from early-type stars is in general correlated with their surface gravity, the H-poor WN stars should have slower winds and narrower lines than the H-free WN stars (see, *e.g.*, Smith et al. 1996; Conti 1999). Thus, the 7 narrow-line stars that Paumard et al. (2001) classify as LBVs could be H-poor WN stars while the broad-line stars, including IRS 13E2, could be H-free WN stars. This is consistent with He/H measurements (Najarro et al. 1997) which correlate narrow-line stars with low He/H ($\lesssim 3$) and broad-line stars with large He/H ($\gtrsim 100$). While LBVs generally also have He/H of less than a few (Crowther et al. 1995), it seems unlikely, even in the peculiar environment of the GC, that 7 LBVs would exist at the same time in the same cluster. Comparison with WR 122, a star still shrouded in ejecta and thought to be just post-LBV, might be useful.

[4] However, Paumard et al. (2001) claim some or even all of these are actually not HeI stars and thus not likely WRs.

Models of the bolometric luminosity and effective stellar temperature of IRS 13E2 ($M_{\rm bol} = -11.2$ mag and $T_{\rm eff} \simeq 29$ kK) place it on the left edge of the Humphreys-Davidson (HD) line, the location on the HR diagram where LBVs are thought to exist. This temperature, as well as the temperature of the other early-type stars in the central parsec, is somewhat colder than the lower limit of traditional WR stars (30kK; Wolf 1989), but, due to the high extinction, determining effective temperature in the GC is notoriously difficult (Dessart et al. 1999). At present only a few central stars have estimated $M_{\rm bol}$ and $T_{\rm eff}$ values; within the relatively large errors, all fall below or are near the HD line. The effect of metallicity on the HD line is unclear but models suggest that high metallicity moves LBVs to lower $L_{\rm bol}$ and $T_{\rm eff}$ (Stothers & Chin 1996). In the future, observations of CO absorption at 2.3μm and H_2O absorption at 1.9μm may better determine $T_{\rm eff}$ and $M_{\rm bol}$ for IRS 13E2 and the other early-type stars in the GC (Blum et al. 1999).

An LBV is often variable across many time-scales and frequencies. Although IRS 13E2 may be marginally variable at the level of $\lesssim 0.1$ mag in K-band (Ott et al. 1999), it is not significantly variable in the mm (Zhao & Goss 1998) nor apparently in the X-ray (Baganoff et al. 2001a). This suggests it has ended its LBV phase, although it may also be merely quiescent. Since it takes $\simeq 3 \times 10^6$ years for a 100 M$_\odot$ star to proceed from the ZAMS through to the final WR phase (Langer et al. 1994), this gives an approximate age of the central cluster.

The high terminal wind velocity ($\simeq 1000$ km s^{-1}) and lack of short-term variability suggests that IRS 13E2 has ended its LBV phase. Tidal disruption by Sgr A* means that any nebula surrounding IRS 13E2 is likely to be short lived after the star becomes a broad-line H-free WN star. In addition, since LBV terminal wind velocities can be lower than $\sim$ 200 km s^{-1} (Najarro et al. 1997; Parker 1997), any GC LBV-spawned nebula will be distorted by stellar motion alone and thus would not appear as symmetrical as, *e.g.*, the Homunculus around η Car.

5.1. Lifetime of an LBV Nebula in the GC

We can crudely estimate the "half-life" of an LBV shell (that is, how long before the two sides of the shell are differentially stretched by a factor of two if they are on separate circular Keplerian orbits) by

$$t \simeq \frac{2D}{v_i - v_o} , \qquad (1)$$

where D is the diameter of the shell and v_i and v_o are the circular Keplerian velocity at the inner and outer edge of the shell, respectively. Assuming the object is near enough

to Sgr A* so that the gravitational potential of the supermassive black-hole is dominant ($\lesssim 3$ pc; Genzel et al. 1996), the circular Keplerian velocity is:

$$v = \sqrt{\frac{GM}{R}} = 100\ R^{-1/2}\ \mathrm{km\ s^{-1}}\ , \tag{2}$$

where R is in pc. Next, assuming $D \ll R$, one finds that t is independent of D:

$$t \simeq 4 \times 10^4 R^{3/2}\ \mathrm{yrs}\ . \tag{3}$$

Thus, for IRS 13E2, any LBV shell is likely to exist for only ~ 2000 yrs after the star's final molting. Since the circular orbital period of an object within a few parsecs of Sgr A* is $6 \times 10^4 R^{3/2}$ yrs, the lifetime of any nebula will be less than an orbit, regardless of R.

If the differential speed between the gas in the Bar and IRS 13E is a few tens of km s^{-1}, a few thousand years is also the time-scale needed for IRS 13E to move from the centre of the mini-cavity to its present location (see Fig. 1 in Coker & Pittard 2000). Since the mm proper motion of the IRS 13E complex points back towards the mini-cavity (Zhao & Goss 1999) this raises the possibility of an association between the two: *e.g.*, did IRS 13E carve out the mini-cavity as it traversed the Bar?

Thus, there is strong evidence from the width of the He line at 2.058μm and the He/H ratio that IRS 13E2 has recently finished its LBV phase and is currently a broad-line H-free WN star. The presence of LBV ejecta may also explain the high absorbing column and if true would place a strong constraint on the time elapsed since becoming a H-free WN star.

6. An Extended Binary System

In order for IRS 13E to be such a strong X-ray source while not being variable on time-scales of days or a year, it is likely to be a wide binary with a period significantly longer than a year. IRS 13E1, a possible massive dwarf O-star, is approximately 0.15$''$ from 13E2 and is a possible companion since much of the mm emission lies between these two sources (Zhao & Goss 1998, 1999). IRS 13E3 is 0.2$''$ distant in projection and, although it has weak Pa-α/HeI emission so that it may be a WR-star in its own right, there is no mm emission directly between IRS 13E3 and IRS 13E2. This implies that even if the three sources compose a triple system, IRS 13E3 is too far away to produce significant emission due to colliding winds.

A very crude estimate of the intrinsic column in a CWB is (Usov 1992; Stevens et al. 1992)

$$N_{\mathrm{H}}^{\mathrm{INT}} \simeq 5 \times 10^{22} \frac{\dot{M}}{dv}\ \ \mathrm{cm^{-2}}\ , \tag{4}$$

where the mass-loss rate $\dot{M}$ is in units of 10^{-5} M$_\odot$ yr^{-1}, the separation d is in units of 10^{13} cm and the wind velocity v is in units of 1000 km s^{-1}. For sensible values of $\dot{M}$ and v, if any significant fraction of our estimated column is intrinsic, d must be less than ~ 100 AU. But the separation between IRS 13E2 and IRS 13E1 corresponds to about 700 AU in projection, which, for a combined 70M$_\odot$ system, implies an orbital period of $\gtrsim 2000$ years. At this separation the CWB shocks are likely to be largely adiabatic and would emit only weakly in the X-ray ($L_{\mathrm{x}} \propto \dot{M}^2 v/d$; Stevens et al. 1992) unless the winds are particularly dense.

However, on the plane of the sky, the IRS 13E complex is part of the Bar in the center of the mini-spiral. Thus, if the complex is located within or behind the dense gas of the Bar, it is possible that much of our estimated column is due to the Bar (which does not lie in front of Sgr A*) rather than the complex itself. In addition, the extinction towards the GC is known to be very patchy on small scales. This suggests that IRS 13E1 and IRS 13E2 may still be companions, but it would also imply that the LBV nebula has at least partially dispersed.

The X-ray luminosities of CWB systems vary with time as well as depending on mass loss rates, wind velocities, and orbital separation. Models of WR 147, an extended CWB with a period of at least a few thousand years, predict $L_{\mathrm{x}} \sim 0.1$L$_\odot$ (Pittard et al. 2001), However, the mass-loss rate of IRS 13E2 is estimated to be more than ten times that of the WR 147 primary. Thus the X-ray luminosity of IRS 13E is consistent with a CWB.

The proper motion of the mm sources in the IRS 13E complex have been measured to be ~ 250 km s^{-1} (Zhao & Goss 1998, 1999). This is consistent with the interpretation that they are high-velocity knots within surrounding stellar ejecta. Observations show that at least one of the mm sources has a spectral index suggestive of emission from ejected circumstellar material from a stellar envelope.

In summary, the heavily absorbed X-ray spectrum of IRS 13E best matches a long period CWB system whose primary has recently exited its LBV phase. Long term monitoring at mm and K-band as well as long-integration *Chandra* observations will help determine precisely what type of binary is contained in the IRS 13E system.

Acknowledgements. This work was supported by PPARC and has made use of NASA's Astrophysics Data System Abstract Service. We gratefully acknowledge helpful discussions with R. Oudmaijer, M. Hoare, S. Stolovy, and J.-P. Maillard.

References

Baganoff, F. K., Bautz, M. W., Brandt, W. N., et al. 2001a, Nat, 413, 45

Baganoff, F. K., Bautz, M. W., Cui, W., et al. 2000, BAAS, 197, 04.02

Baganoff, F. K., Maeda, Y., Morris, M., et al. 2001b, ApJ, submitted (astro-ph/0102151)

Blum, R. D., Ramírez, S. V., & Sellgren, K. 1999, in ASP Conf. Ser. 186: The Central Parsecs of the Galaxy, ed. H. Falcke, A. Cotera, W. Duschl, F. Melia, & M. Rieke (San Francisco: ASP), 291

Carr, J. S., Sellgren, K., & Balachandran, S. C. 2000, ApJ, 530, 307

Cash, W. 1979, ApJ, 228, 939
Chlebowski, T. & Garmany, C. D. 1991, ApJ, 368, 241
Chlebowski, T., Harnden, F. R., & Sciortino, S. 1989, ApJ, 341, 427
Clénet, Y., Rouan, D., Gendron, E., et al. 2001, A&A, 376, 124
Coker, R. F. & Pittard, J. M. 2000, A&A, 361, L13
Conti, P. S. 1999, New Astronomy, 4, 489
Corcoran, M. F., Ishibashi, K., Swank, J. H., & Petre, R. 2001, ApJ, 547, 1034
Crowther, P. A., Smith, L. J., Hillier, D. J., & Schmutz, W. 1995, A&A, 293, 427
Dessart, L., Crowther, P. A., Smith, L. J., & Bohannan, B. 1999, in IAU Symp. 193: Wolf-Rayet Phenomena in Massive Stars and Starburst Galaxies, ed. K. A. van der Hucht, G. Koenigsberger, & P. R. J. Eenens (San Francisco: ASP), 476
Figer, D. F., McLean, I. S., & Morris, M. 1999, ApJ, 514, 202
Garmire, G., Feigelson, E. D., Broos, P., et al. 2000, AJ, 120, 1426
Genzel, R., Thatte, N., Krabbe, A., Kroker, H., & Tacconi-Garman, L. 1996, ApJ, 472, 153
Humphreys, R. M. & Davidson, K. 1994, PASP, 106, 1025
Krabbe, A., Genzel, R., Eckart, A., et al. 1995, ApJ, 447, L95
Langer, N., Hamann, W.-R., Lennon, M., et al. 1994, A&A, 290, 819
Libonate, S., Pipher, J. L., Forrest, W. J., & Ashby, M. L. N. 1995, ApJ, 439, 202
Lutz, D., Krabbe, A., & Genzel, R. 1993, ApJ, 418, 244
Melia, F. & Falcke, H. 2001, ARA&A, 39, 309
Mewe, R., Gronenschild, E. H. B. M., & van den Oord, G. H. J. 1985, A&AS, 62, 197
Meynet, G. & Maeder, A. 2000, A&A, 361, 101
Moffat, A., Corcoran, M., Stevens, I., et al. 2001, ApJ, in press
Moneti, A., Stolovy, S., Blommaert, J. A. D. L., Figer, D. F., & Najarro, F. 2001, A&A, 366, 106
Mowlavi, N., Schaerer, D., Meynet, G., et al. 1998, A&AS, 128, 471
Najarro, F., Hillier, D. J., & Stahl, O. 1997, A&A, 326, 1117
Najarro, F., Krabbe, A., Genzel, R., et al. 1997, A&A, 325, 700
Ott, T., Eckart, A., & Genzel, R. 1999, ApJ, 523, 248
Pallavicini, R., Golub, L., Rosner, R., et al. 1981, ApJ, 248, 279
Parker, J. W. 1997, in ASP Conf. Ser. 120: Luminous Blue Variables: Massive Stars in Transition, ed. A. Nota & H. Lamers (San Francisco: ASP), 368
Paumard, T., Maillard, J. P., Morris, M., & Rigaut, F. 2001, A&A, 366, 466
Pittard, J., Stevens, I., Williams, P., et al. 2001, A&A, submitted
Ramírez, S. V., Sellgren, K., Carr, J. S., et al. 2000, ApJ, 537, 205
Reid, M. J. 1993, ARA&A, 31, 345
Rieke, M. J. 1999, in ASP Conf. Ser. 186: The Central Parsecs of the Galaxy, ed. H. Falcke, A. Cotera, W. Duschl, F. Melia, & M. Rieke (San Francisco: ASP), 32–38
Schaller, G., Schaerer, D., Meynet, G., & Maeder, A. 1992, A&AS, 96, 269
Schlegel, E. M., Serlemitsos, P. J., Jahoda, K., et al. 1993, ApJ, 407, 744
Sellgren, K., McGinn, M. T., Becklin, E. E., & Hall, D. N. 1990, ApJ, 359, 112
Seward, F. D., Butt, Y. M., Karovska, M., et al. 2001, ApJ, 553, 832
Simpson, J. P., Colgan, S. W. J., Rubin, R. H., Erickson, E. F., & Haas, M. R. 1995, ApJ, 444, 721
Smith, L. F., Shara, M. M., & Moffat, A. F. J. 1996, MNRAS, 281, 163
Stevens, I. R., Blondin, J. M., & Pollock, A. M. T. 1992, ApJ, 386, 265
Stolovy, S. R., McCarthy, D. W., Melia, F., et al. 1999, in ASP Conf. Ser. 186: The Central Parsecs of the Galaxy, ed. H. Falcke, A. Cotera, W. Duschl, F. Melia, & M. Rieke (San Francisco: ASP), 39
Stothers, R. B. & Chin, C. 1996, ApJ, 468, 842
Tamblyn, P., Rieke, G., Hanson, M., et al. 1996, ApJ, 456, 206
Usov, V. V. 1992, ApJ, 389, 635
van der Hucht, K. A. 2001, New Astronomy Reviews, 45, 135
van der Hucht, K. A., Williams, P. M., Setia Gunawan, D. Y. A., et al. 1994, in ASSL Vol. 187: Frontiers of Space and Ground-Based Astronomy, ed. W. Wamsteker, M. Longair, & Y. Kondo (Dordrecht: Kluwer), 565
van Genderen, A. M. 2001, A&A, 366, 508
Walborn, N. R. 1989, in IAU Colloq. 113: Physics of Luminous Blue Variables, ed. K. Davidson, A. Moffat, & H. Lamers (Dordrecht: Kluwer), 27
Waldron, W. L., Corcoran, M. F., Drake, S. A., & Smale, A. P. 1998, ApJS, 118, 217
Wolf, B. 1989, A&A, 217, 87
Yusef-Zadeh, F., Cotera, A., Fruscione, A., et al. 2001a, BAAS, 198, 87.09
Yusef-Zadeh, F., Law, C., Wardle, M., et al. 2001b, ApJ, submitted (astro-ph/0108174)
Zhao, J. . & Goss, W. M. 1999, in ASP Conf. Ser. 186: The Central Parsecs of the Galaxy, ed. H. Falcke, A. Cotera, W. Duschl, F. Melia, & M. Rieke (San Francisco: ASP), 224
Zhao, J. & Goss, W. M. 1998, ApJ, 499, L163